

University of Illinois at Urbana - Champaign
Department of Electrical and Computer Engineering

PV Autonomous Golf Ball Retriever

Design Review

Team 20

Kevin Dluzen, Jonathan Hall, Diyang Qiu

TA: Alex Suchko

Table of Contents

1. Introduction	
1.1 Objective	3
1.2 Features.....	3
1.3 Benefits	3
2. Block Diagram Descriptions/Schematics	
2.1 Vision/controller Module.....	5
2.1.1 Camera.....	5
2.1.2 CVS (main controller).....	5
2.1.3 Ball counter sensor.....	7
2.1.4 PIC microcontroller.....	7
2.2 Motor control module.....	7
2.2.1 H-bridge.....	8
2.2.2 Motors.....	10
2.3 Power/PV module.....	10
2.3.1 PV panel.....	10
2.3.2 12V battery.....	10
2.3.3 battery controller.....	11
2.3.4 Power Distribution.....	11
2.3.5 Boost converter.....	11
3. Requirements	
3.1 Testing procedures.....	11
4. Ethics	
4.1 Ethical Issues.....	14
5. Cost Analysis and Schedule	
5.1 Cost Analysis.....	14
5.1.1 Labor Cost.....	14
5.1.2 Parts Cost.....	15
5.2 Schedule.....	16
6. Citations	
7. Appendices	
A. Dayton motor rating.....	19
B. PSPICE simulation.....	20
C. Weight calculation.....	21

1. Introduction

1.1 Objective

The goal of our project is to build a solar powered autonomous robot that picks up and stores golf balls. This robot would be used on golf courses and driving ranges and replace the man operated vehicles that can be costly and bad for the environment. Our robot will use a camera that connects to a vision processing unit called the CVS(compact vision system). The CVS will identify the location of the nearest ball and direct two front motors to the ball. The ball will be picked up by a rotating wheels and stored in a container on the robot.

1.2 Features:

- Solar powered battery charging
- Fully autonomous collection, no user input needed to monitor robot
- Nonstop golf ball collection using axial mechanical retrieval method
- Image processing allows for more efficient routes to golf ball retrieval to be implemented
- Fully electric battery powered system (not gasoline)
- Automated halt when golf ball capacity reached

1.3 Benefits:

- Time savings from having to pick up each individual ball
- Green solution to golf ball retrieval
- Easy to use since it has autonomous pickup
- Reduces wear on green as opposed to heavy collection vehicles
- More efficient routes to balls are calculated resulting in less energy wasted
- Less initial capital cost than current methods
- Ability to retrieve balls in compact locations due to high maneuverability

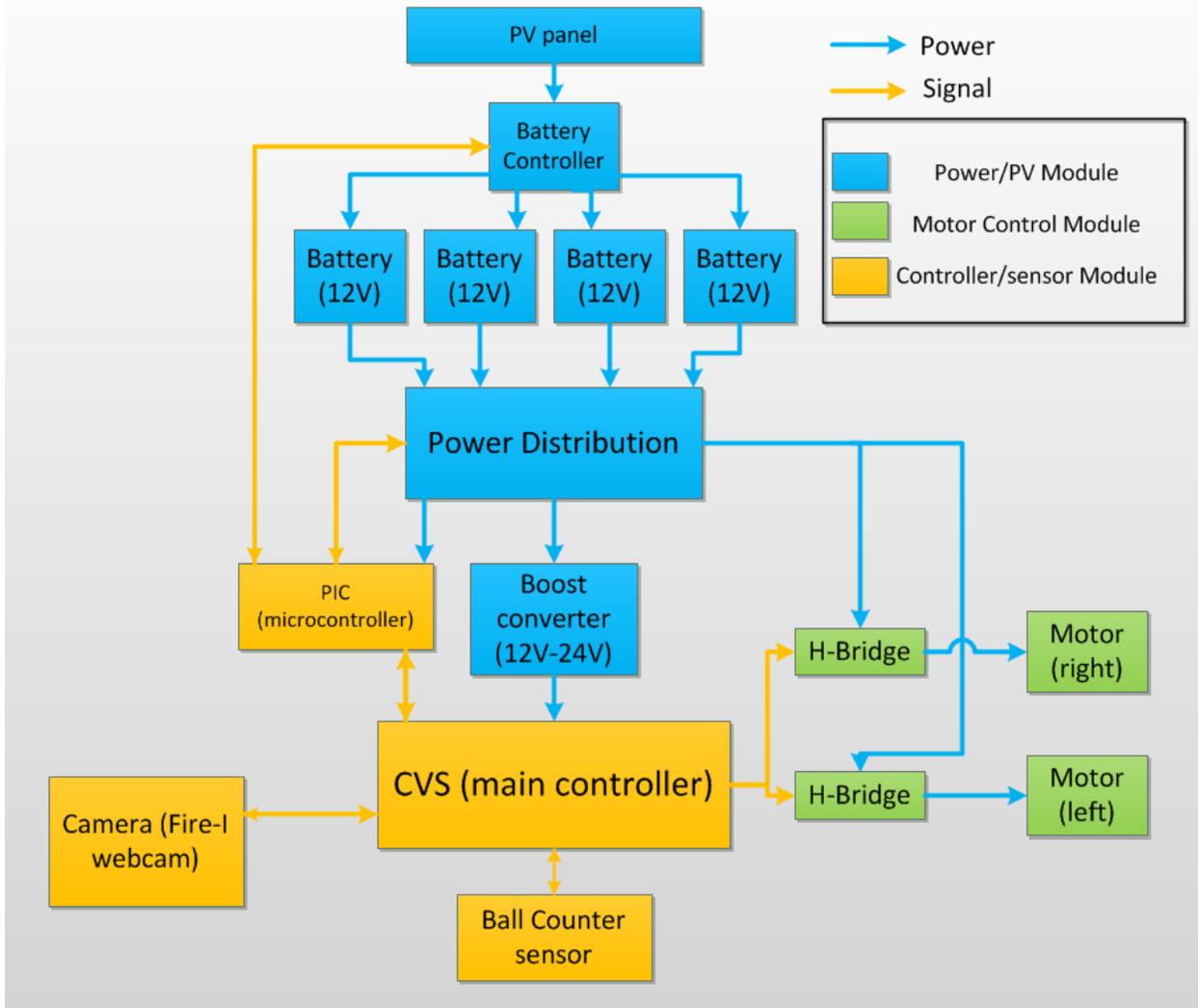


Figure 1 : Block diagram

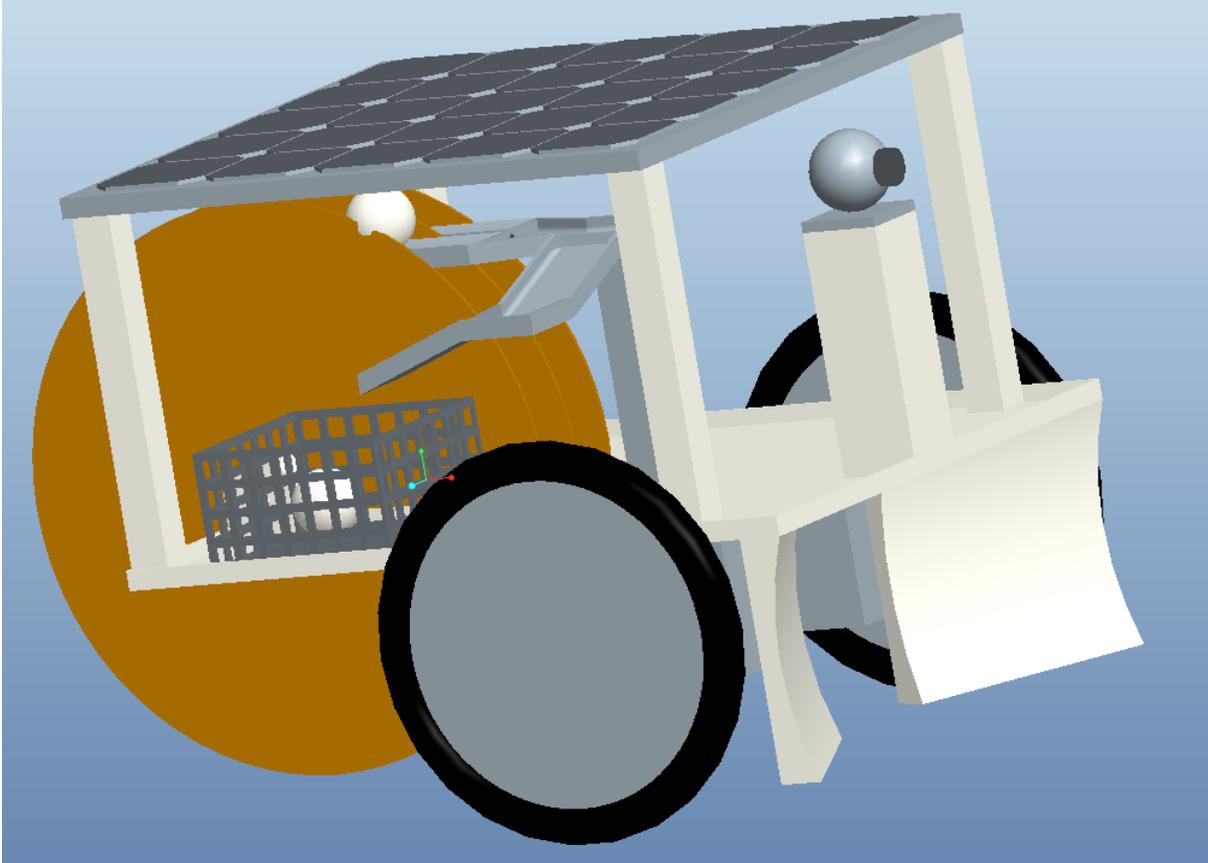


Figure 2 : 3D CAD model

2. Block Diagram Descriptions/Schematics

2.1 Vision/controller Module

2.1.1 Camera

The camera purchased is a Fire-i digital camera. It has a max fps of 30 and a resolution of 640x480. The camera will communicate with the CVS (compact vision system) via a FireWire connection. It will be positioned at the front of the robot and placed on a stand approximately 6 inches tall as shown in Figure 2. The orientation of the camera will be such that it is able to just see the front end of the robot so that balls near the robot can be located

2.1.2 CVS (main controller)

The CVS (compact vision system) will take the FireWire input from the camera and run LabVIEW internally to identify the position of the ball closest to the robot.. The image processing flowchart is shown in Figure 3 below. First, the color picture is

converted to a grey scale image. Next, a threshold grey scale value is used to split the image into binary. This will split the image into a red/black image shown in Figure 3 step 3, the black image will be the background and the red image will be the golf balls and noise. Next, shape recognition and blob sizes will be taken into account to eliminate any noise. This will involve looking for circular shapes and removing red blobs that are too small or too large to be golf balls. Next, the centroids for the remaining red shapes, will be found, this will give the pixel coordinates for each object. The closest ball will correspond to the centroid with the lowest horizontal pixel due to the orientation of the camera. Once the nearest ball location has been identified, the CVS will output the corresponding PWM(Pulse Width Modulation) signal from its I/O ports to each h-bridges to control which direction the robot needs to move based on the horizontal and vertical pixel.

The CVS will also be responsible for controlling the ball counter module. One I/O from the CVS will measure the voltage drop from the photoresistor. It will count the number of low signals from the photoresistor and stop the motors once the maximum number of balls have been retrieved.

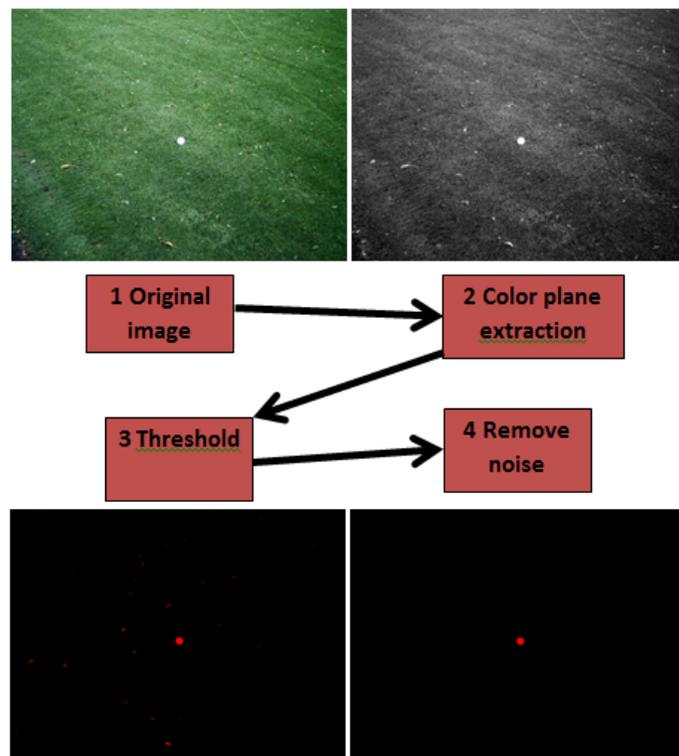


Figure 3 : Image processing flowchart [1]

2.1.3 Ball Counter Sensor

The ball counter sensor will be placed on the “slide” just before the balls enter the storage container shown in Figure 2. An LED will be placed on one side of the slide and remain constantly on while a photoresistor will be placed on the other side. When a ball passes between the two, a momentary small voltage drop will be seen in the photoresistor. An op amp will amplify the signal to match up with the digital input of the CVS.

2.1.4 PIC microcontroller

The PIC microcontroller will act as the communication between the battery controller and the power distribution circuit. The power distribution circuit will output the voltage of the battery currently powering the system. If this voltage begins to drop then the PIC sends a command to the solar controller to switch the battery it is currently charging. The PIC simultaneously sends another signal to the power distribution circuit telling it to switch the battery cell currently charging the robot.

2.2 Motor control module

2.2.1 H-bridge

The H-Bridge is necessary in order to interface the micro-controller with the motors. This is done in order to isolate the controls from the consumption of the power. In order to take the signals from the controller and adapt them such that they are usable by our power bridge we will use a HIP4081A. The HIP4081A is a high frequency Full Bridge N-Channel FET Driver. This allows for the Power Mosfets in the Power Bridge to be correctly bootstrapped and adds extra elements of protection to ensure that the Power bridge does not create any shorting conditions (shoot through conditions). Going from the FET Driver to the Power Bridge as seen in Figure 4. it is clear that the system is designed with an modular interface in mind. The H-bridge and motor control system is able to take in PWM signals in which can range from 3-12V (Modified TTL) which allows us future expansion and ability to use a range of logic voltages. The design of this H-Bridge also allows us to have a varied input to the battery if different motor conditions were chosen. Since the HIP4081A can source approximately 1A from each pin there are measures taken in order to limit the current by use of a gate resistor. This reduces

the heating of the chip and limits the gate current to something more reasonable. Delay can be a large problem in the controlling of a motor and in order to speed up the turn off time of the FETs schottky diodes are attached in parallel to the gate resistors. Lastly Transient Voltage Suppressors are added in parallel to the lower FETs to ensure that high current spikes do not damage the circuit.

The actual control of the motor is done in a way in which is described in Table 1. This method allows us to implement the function of Forward, Reverse, Brake, and Disable for each of the motors. This paired with the concept of PWM and duty cycle we are able to effectively control speed, direction, and braking.

Table 1. Control Signals

AHI	BHI	ALI	BLI	Disable	Function
1	1	0	PWM	0	Forward
1	1	PWM	0	0	Reverse
1	1	0	0	0	Brake
X	X	X	x	1	Disabled

We have specified that there are wishes to operate at full 100% duty cycle without causing harm to the motor or heating beyond 40 C. Duty cycle is the ratio of the duration of the event to the total period.

2.3 Power/PV module

2.3.1 PV panel

The PV solar panel is a 10 watt crystalline solar panel, the main factors for choosing this panel is directly related to the physical real estate of our robotic unit. The 19" * 11.2" solar panel will match the basic size of the chassis. It is the core element for our green energy source of our project.

Considering the portability of the vehicle, the bigger solar panels will not match our system, but a smaller panel will not allow us for the power generation necessary to charge the system. Therefore, we found a balance between those two considerations.

2.3.2 12V battery

Four 12V rechargeable sealed lead acid batteries will be used in this Project. The battery's will be the power source for the entire system. They will be able to be recharged through the use of the solar cells as well as through a power outlet. Since a battery can not be charged and used at the same time, we require at least 2 batteries, one to power the system and one to receive power from the solar panel. Also, we determined that 1 battery will not be provide enough power to our system so we need an extra battery to provide adequate power. This comes to a total of four batteries split into two banks. One bank powers the robot and the other receives power from the PV panel.

3.3 Battery Controller

The battery controller works functionally as a switch. It decides which battery bank will be charged during the daily work. The PIC microcontoller will send a signal to the battery controller indicating what battery cell to charge with the solar panel. Also, the battery controller will regulate the voltage from the solar panel to protect the battery from being overcharged.

2.3.4 Power Distribution

The power distribution block will control which battery bank is powering the system. It will be connected all the batteries and switches which battery bank is powering the system. The block will output the current voltage of the battery cell powering the system to the PIC and will receive a signal from the PIC when the battery cells are to be switched.

2.3.5 Boost converter

Since the rated voltage for the CVS is 24 Volt, we need to convert the 12V battery to 24V +/- 10%. A boost converter is needed to complete this requirement.

3. Requirements

3.1 Testing Procedure

Requirement	Verification
<p>1. CVS outputs PWM to motors corresponding o pixel location of nearest ball.</p> <p>a. The CVS will locate 90% of balls within the cameras FOV</p> <p>b. The CVS will accurately identify the nearest ball 100% of the time</p> <p>c. The CVS will accurately output the PWM needed for each motor</p> <p>d. Camera will not go below 5 fps</p>	<p>1. The camera must be hooked to the CVS and be oriented as it would be on the robot. Balls will be placed within the cameras FOV on a piece of turf or outside in the grass. An oscilloscope will connect to the PWM outputs of the CVS.</p> <p>a. Connect a monitor to the CVS and determine which balls have been identified and which were missed. Also look at how many fps the camera is outputting and reduce code length if fps is too low</p> <p>b. From the monitor output, the nearest ball will have a crosshair placed over it and pixel location shown. We will determine whether the ball identified is indeed the closest ball.</p> <p>c. Example pixel values will be coded into the CVS and we will measure the corresponding output from the CVS using an oscilloscope and determine whether the PWM is accurate.</p> <p>d. Find the fps from the monitor and reduce code length/complexity if average fps is lower then 5.</p>
<p>2. Battery Controller will control the PV panel voltage and send the power to the correct battery</p> <p>a. The output voltage from the solar panel must be between 11.8V and 12.2V</p> <p>b. The controller switches the output+ mode depending on the input from the micro-</p>	<p>2. The solar controller will connect to both battery banks and be able to switch between the two based on the input signals from the microcontroller while the voltage from the panel remain steady</p> <p>a. A discharged battery will connect to the PV panel and solar controller and a voltmeter</p>

<p>controller.</p>	<p>will measure the voltage from the solar panel b. The controller will be tested by implementing a high signal in which the output should electrically connect battery bank 1 to the PV panel and electrically isolate battery bank 2 from the Panel and vice versa.</p>
<p>3. Power Distribution will connect at most one battery bank to the robot and provide be able to switch between both battery banks a. the unit must be able to electrically connect one (or none) of the battery banks at a time and keep the output voltage between 11.5V and 12.5V b. the unit must be able to convert the voltages from the battery banks linearly to a readable output of 0-5.5V</p>	<p>3. The power distribution testing will consist of inputting a high/low signal to the circuit and testing whether it switches battery cells without momentarily shorting them. a. We will signal the circuit to switch and monitor the voltage of the output. We will also look at the batteries being switched and ensure no momentary short circuits between them. b. the maximum expected voltage will be connected to our step down circuit and the output voltage will be measured.</p>
<p>4. Motor Delivers Torque to wheels to successfully pick up balls a. Hbridge accepts input PWM values from 3-12V logic b. The Controller must output PWM suitable for the FET driver (3-12V) c. Must not collect more than 30 balls (proper max ball sensing) d. Motor must not overheat (40°C) e. Must operate continuously at 90% duty cycle f. Motor must be able to speed the unit at a minimum of 0.5mph</p>	<p>4. This results from several moments of stress testing on the motor and motor drive components. 10-13V will be applied to battery terminals of the power bridge and the micro controller will be set to a particular Duty cycle a. The power bridge will be tested with 3-12V logic to ensure that it does indeed provide the correct conductive path necessary for motor control signals b. The controller will be tested using the power bridge and detecting the output waveforms on the oscilloscope. The output waveforms must produce a PWM with ranges of 10-13V and within +- 5% duty cycle. c. The ball sensor will be tested in conjunction with the motors to ensure no more balls will be added after 30 balls have been collected. This will be done by testing the disable signal and making sure that 12V is not being supplied to the motors. d. The motor will not be attached to the motor control unit (while loaded) and will be run continuously at 100% for 10 mins and</p>

	<p>temperature and results will be taken</p> <p>e. Again, the above test will be taken yet again but for longer durations and with a 90% duty load</p> <p>f. Now fully loading the vehicle this testing will take place in the field to ensure that the unit has the ability to move equal to or greater than 0.5mph, this will be taken directly from a distance over time relationship</p>
<p>5. Solar Panel</p> <p>a. The output voltage should be 11.5 to 12.5Volts.</p> <p>b. The power generated by the panel for 8 hrs of incident sunlight will provide the energy requirement of 1hr of continuous use.</p>	<p>5. The solar panel will be connected to a depleted battery and will be able to charge the battery to the desired voltage (11.5V-12.5V) within the specified time</p> <p>a. The output voltage of the solar panel under max incident sunlight will be measured by the multimeter.</p> <p>b. The solar panel will be tested under ideal incident solar conditions and the energy transfer will be calculated using a multimeter for 1 hour. This information will be extrapolated to satisfy the 8hr requirement.</p>
<p>6. Boost Converter - should give an output voltage of 21.6-26.4V from a 11-13V input</p>	<p>6. the boost converter will receive inputs from the battery banks ranging from 11-13V and the output voltages will remaining the specified voltage ranges (21.6-26.4V)</p>

4. Ethics

4.1 Ethical Issues

Ethics is an important concern when designing an autonomous robot. The first code in the IEEE code of ethics states “to accept responsibility in making decisions consistent with the safety, health, and welfare of the public”. Our device will have an emergency stop button that will halt the motors in emergency cases. However, because our vehicle is autonomous, there is no human supervision. Our robot will not be able

detect humans or animals and currently has no way of stopping when it collides with a large object. From our calculations, we have determined that the maximum momentum of our robot will not harm or knock down the average human adult.

5. Cost Analysis and Schedule

5.1 Cost Analysis

5.1.1 Labor Cost

Name	Rate	Hours	Hours*2.5	Total (\$)
Jonathan Hall	\$35.00/hr	240	600	\$21,000
Diyang Qiu	\$35.00/hr	240	600	\$21,000
Kevin Dluzen	\$35.00/hr	240	600	\$21,000
			Total:	\$63,000

5.1.2 Parts Cost

Part	Quantity	Unit Cost (\$)	Total (\$)
NI CVS 1456	1	4409.00	4409.00
Fire-i digital camera	1	98.00	98.00
Golf Balls	30	0.75	22.50
Dayton Motor 1LPV3A	2	208.00	208.00
Wheels and Hubs	2	25.00	50.00
Motor Coupling	2	20.00	40.00
Mechanical Frame/Parts	1	300.00	300.00
Solar Panel 19" * 11.2"	1	60.00	60.00
Battery Controller	1	30.00	30.00
Photoresistor	1	2.00	2.00
LED	1	0.30	0.30

12 V Battery	2	20.00	40.00
Boost Converter(12V-24V) 1.5A rated	1	30.00	30.00
PIC microcontroller	1	3.00	3.00
		Total:	5262.80

H bridge parts list

Name (Part No.)	Description	Quantity	Price/unit (\$/unit)	Price \$
HIP4081A	Fet Driver	2	\$3.50	\$7.00
Power Mosfet	PowerFet	8	\$2.50	\$20.00
Fast Schottky Diodes	Fast Sdiode	8	\$0.15	\$1.20
1.5KESICA	TVS Diode	6	\$0.74	\$4.44
1A 100V Diode	Source Return Diode	4	\$0.80	\$3.20
1.0uF 50V Cap	Source Return Cap.	6	\$0.50	\$3.00
.47uf 50V Cap	Voltage Regulator Cap.	2	\$0.63	\$1.26
10kohm Resistor	Resistor	12	\$0.04	\$0.48
14kohm Resistor	Resistor	2	\$0.10	\$0.20
90.9kohm Resistor	Resistor	2	\$0.10	\$0.20
249kohm Resistor	Resistor	4	\$0.10	\$0.40
Board-misc		1	\$8.00	\$8.00
Terminal connectors		2	\$1.00	\$2.00
Headers		2	\$1.00	\$2.00
Total				\$53.38

Total cost = Labor + Parts = \$63,000 + \$5316.18 = \$68316.20

5.2 Schedule

Week	Tasks
2/6 - 2/12	Kevin - Proposal : Image capture module, mechanical module Jon - Proposal : Motors control module Diyang - Proposal : Solar/power module

2/13 - 2/19	Kevin - Research cameras/CVS Jon - Research motors/H-bridge Diyang - Research Battery/solar panels
2/20 - 2/26	Kevin - Prepare design review Jon - Simulate H-bridge Diyang - Order solar panels/controller
2/27 - 3/4	Kevin - Code CVS to recognize balls Jon - Complete/debug H-bridge design Diyang - Interface single battery with solar cell
3/05 - 3/11	Kevin - Program CVS to output signals to H-bridge Jon - Construct PCB schematic of H-bridge and place order Diyang - Create switching mechanism from solar cells to battery
3/12 - 3/18	Kevin - Code motor commands from ball location/individual progress report Jon - Code microcontroller for H-bridge/individual progress report Diyang - Finish solar controller schematic/individual progress report
3/19 - 3/25	SPRING BREAK
3/26 - 4/1	Kevin - Test/debug image capture module Jon - Test/debug mechanical control module Diyang - Test/debug solar and power module
4/2 - 4/8	Kevin - Construct mechanical chassis and golf ball storage unit Jon - Design of ball pickup mechanism Diyang - Begin power distribution circuit

4/9 - 4/15	Kevin - code and construct golf ball detection sensor Jon - organize/place components onto robot Diyang - Finish coding/simulating power distribution module
4/16 - 4/22	Kevin - Prepare for demo and finish testing and debugging of entire robot Jon - Finish all system integration and have all components added Diyang - test/debug entire power distribution module
4/23 - 4/29	Kevin - Final test run preparation Jon - Prepare presentation Diyang - Write final report
4/30 - 5/6	Kevin - Finalize report Jon - Disassemble mechanical structure Diyang - Disassemble circuits

6. Citations

[1] Wxman81. "Lawn Care Forum." Web. 21 Feb. 2012. <<http://forums2.gardenweb.com/forums/load/lawns/msg0800293317869.html>>.

[2] Lloyd, Sonny, Matt McFadden, Don Jennings, and Robert Doerr. *OSMC Project Documentation V4 25*. Xtreme Motor Control, 30 Mar. 2002. PDF.

[3] "IEEE Code of Ethics." 7.8 *IEEE Code of Ethics*. IEEE. Web. 26 Feb. 2012. <www.ieee.org/>.

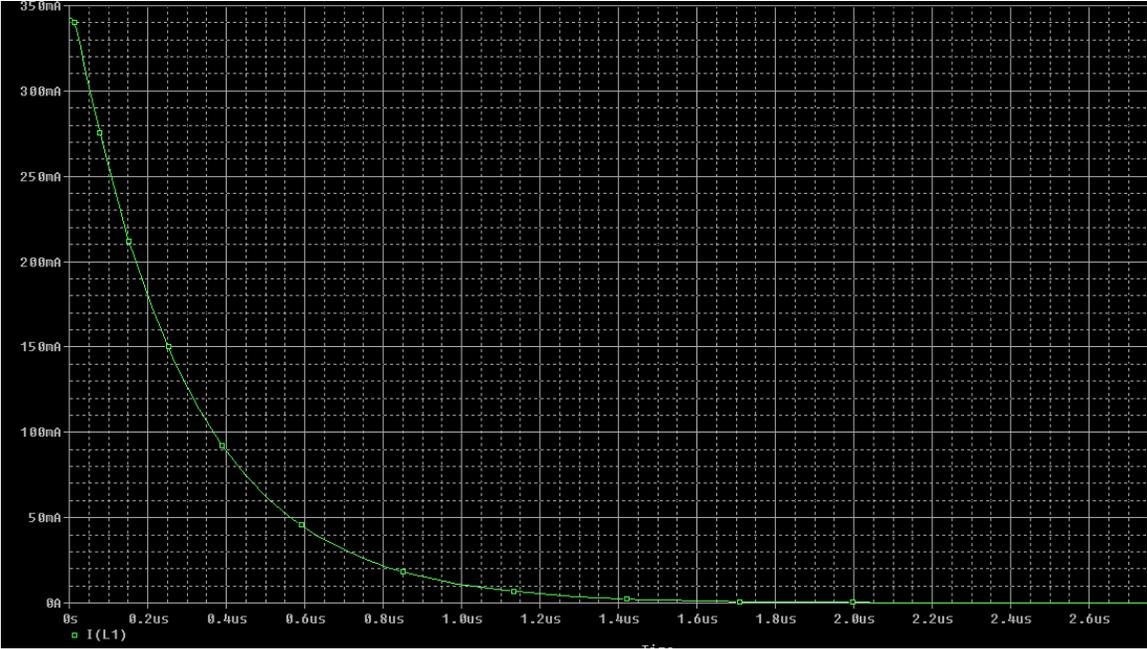
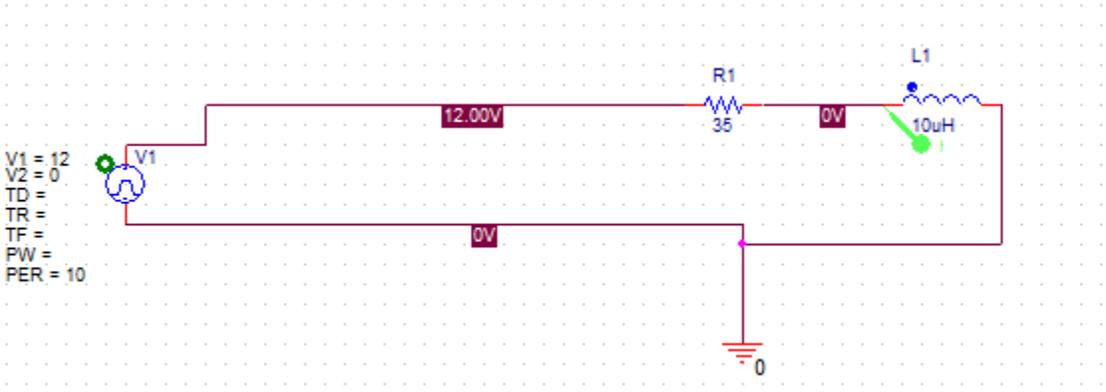
[4] *HIP4081A*. Intersil, July 2004. PDF.

7. Appendices

A: Dayton Motor Ratings



B: Pspice simulation



C: Weight Calculations

Motor Control Module Fermi Calculations

Note: For these calculations we will take three different loading scenarios using different values for the weight of the robotic unit. This will serve as a guiding investigation to the general size of the robotic unit. We will take a scenario to have the minimal specs to meet the requirements for the project. Another scenario will be at the top end of the spectrum giving us more range and weight than necessary and the mid range will be right in the middle.

Weight Investigation						
Item	Weight A (lb)	Note A	Weight B (lb)	Note B	Weight C (lb)	Note
Battery	6	12 V from lab	6	12 V from lab	12	2x 12V from lab
Motors	4	Small 4lb	10	2x 5 lb from lab	20	2 x 10lb from lab
Balls	3.0375	30 golf balls	5.0625	20 golf balls	10.125	100 golf balls
Chassis/Wheels	3	Light	5	Medium	10	Heavy
Ball Retrieval Mech.	1	Smaller system	2	large system	3	Longer Pickup
Solar Panel	7	Tiny Solar Panel	14	Half size Coleman	28	Coleman SP
TOTALS	24.0375		42.0625		83.125	whoa

DC Motor Specs

$$F = MA$$

$$A = \frac{2 \text{ ft}}{s^2} = \frac{.66096 \text{ m}}{s^2}$$

$$F_s = 10.903 \text{ kg} * \frac{.66096 \text{ m}}{s^2} = 7.206 \text{ N}$$

$$F_m = 19.079 \text{ kg} * \frac{.66096 \text{ m}}{s^2} = 12.610 \text{ N}$$

$$F_e = 37.704 \text{ kg} * \frac{.66096 \text{ m}}{s^2} = 24.920 \text{ N}$$

$$F_u = 3.603 \text{ N}$$

$$F_b = 6.305N$$

$$F_c = 12.460N$$

$$\text{Torque} = F \times D$$

$$R_{\text{wheel}} = 5" = 0.127m$$

$$T_a = 3.603 * .127 = .4576Nm = 4.050in-lbs$$

$$T_b = 6.305 * .127 = .800735Nm = 7.0871in-lbs$$

$$T_c = 12.46 * .127 = 1.58242Nm = 14.006in-lbs$$

$$V = RPS * 2\pi R$$

$$1 \frac{ft}{s} = 0.30475 \frac{m}{s}$$

$$0.30475 = RPS * .798$$

$$RPS = 3.819$$

$$RPM = 22.915$$

$$\text{Supplied } V = 12V$$

$$\text{Output Torque} = \text{Input Torque} * \text{Gear Reduction} * \text{Transmission Efficiency}$$